PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Fuel Cell Pack Construction

We, ESSO RESEARCH AND ENGINEERING COMPANY, a Corporation duly organised and existing under the laws of the State of Delaare, United States of America, of Elizabeth, New Jersey, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to improvements in fuel cells and has particular application to fuel cells wherein multiple units are to be connected in series. The invention reates more particularly to a compact fuel cell pack construction adapted to produce maximum power for a cell construction of minimum size or volume.

Numerous proposals have been made in the prior art to build fuel cells capable of oxidizing a suitable fuel to produce electrical current for power purposes. The principle of the fuel cell is well established scientifically, but it has not been developed commercially for several reasons. Some of these reasons are that it has not been found possible to produce electric power in substantial quantity at economical costs, polarization has been excessive, and it has been difficult to realize theoretical voltages even at low current output. At higher current output, voltages have dropped so low in most instances that investigators have been discouraged and have discontinued efforts to product economical commercial fuel cell units.

Another problem has been that of designing a fuel cell construction which will produce a substantial amount of power from a unit of reasonable size. The commercial success of a fuel cell, as of any other power-producing device, depends upon its power output and the ratio of its power output to its size, cost and convenience.

The present invention is designed to improve the power to volume ratio of fuel cells very substantially. Coupled with other improvements which have been made recently, these represent substantial advances towards production of a truly commercial fuel cell.

It is one object of the present invention to improve at the same time the compactness and performance characteristics of a fuel cell which comprises a plurality of fuel electrodes and a plurality of oxidizing electrodes. This is accomplished by using single or common electrical conductor means for adjacent fuel and oxidizing electrodes which operate separately on separate electrolyte contact areas. In effect, this puts the adjacent unit cell elements in series connection so that their electro-potential output is added in series.

An additional object is to maintain continuous electrical contact between selected electrodes in a fuel cell assembly or pack at widely varying temperatures despite differential thermal expansion of the housing, electrodes or other elements. A related object is to utilize resilient contact elements for this purpose.

Another object is to make use of a single conductor means or group of means connecting adjacent fuel and oxidizing electrodes as just described, to serve also as a partition, or to be assembled with and supported by a partition member to separate incoming fuel from the air or other oxidizing material, each of which thus comes separately into contact with its appropriate electrode.

A further object is to provide a plurality of electrical contacts over the entire area of electrodes of substantial surface area so as

[*Pric*

to maintain substantially identical electric potential throughout the entire area:

Additional objects are the provision of suitable electrical contacts for maintaining continuous electrical contact with and giving mechanical support to appropriate electrode elements, a novel way of combining such contacts with supporting partition elements, the assembly at the same time being of such design as to permit the free but separate passage of fuel and air or other oxidizer gas to their respective electrodes.

The invention will be more clearly understood by reference to the accompanying drawings showing several modifications.

In the attached drawings, Fig. 1 is a vertical fragmentary sectional view through a multi-unit fuel cell illustrating one form of the invention;

Fig. 2 is a detailed view, highly magnified indicating a hypothetical operation of a cell for illustrative purposes;

Fig. 3 is a fragmentary vertical sectional view through a modified cell;

Fig. 4 is a fragmentary front elevational view of a conductor-partition element formed with resilient protuberances for contact with fuel cell electrode elements;

Fig. 5 is a transverse sectional view taken substantially along the line 6—6 of Fig. 4;

Fig. 6 represents another modification showing fuel cell electrodes having their electrolyte contact faces treated to substantially increase effective surface area;

Fig. 7 is a fragmentary sectional detail showing another form of conductor and electrode contact construction;

Fig. 8 is a fragmentary perspective view of the device of Fig. 7 showing only one of the electrode contact elements;

Fig. 9 is a fragmentary sectional view showing another form of resilient electrode conductor and partition element construction; and

Fig. 10 is still another fragmentary sectional view showing a further modification.

Referring first to Fig. 1, there are shown a plurality of oxidizer or air electrodes 11 and a plurality of fuel electrodes 13. In this instance, three of each are shown, but other numbers can be used and usually the total will be much greater as will be obvious.

Between each pair of electrodes 11 and 13 which comprise a unit cell, a suitable electrolyte 15 is contained. This electrolyte may be of any conventional type, either alkaline or acidic or in some cases relatively neutral in pH. If the oxidation of fuel involves production of carbon dioxide as it does where hydrocarbon or other carbon containing fuels are consumed, the electrolyte should be of a type which will reject and not absorb the carbon dioxide. Hence, it will be mentioned herein as an acidic type electrolyte 15 which may, for example, be a solution of sulfuric acid or other suitable acid. It will be understood that other carbon dioxide rejecting electrolytes may also be used in some cases, e.g. carbonate, bi-carbonate solutions, mixtures, etc.

Between each fuel electrode of one cell and the oxidizer electrode of the next adjacent cell in the multi-cell unit, there is placed a partition 21. There are two of these shown in Fig. 1 and since they are identical, only one need be described. The partition consists of a continuous sheet composed of or containing a core or web of electrically conductive material such as metal, e.g. copper, brass, aluminum or silver-plated copper, which is embossed or drawn into a waffle-like pattern having electrically conducting protuberances 23 and 25 on its respective faces. These protuberances extend respectively into electrical contact with the oxidizer electrode 11 and the fuel electrode 13 so that any voltage potential on these electrodes will be identical with that on the partition-conductor member 21. The protuberances or contacts 23, 25 are resilient so as to maintain good contact at widely varying temperatures which might cause relative movement due to differential expansion of elements of the fuel cell, e.g. the housing, the electrodes, or their supports, etc.

It will be understood that the partition member 21 is so formed that the oxidizer, a fluid which is preferably air or oxygen but may be other gaseous or even liquid material, can pass freely along and in contact with an electrode 11 while a separate fluid fuel such as hydrogen, hydrocarbon in liquid or vapor form, or alcohol liquid or vapors, can pass freely in contact with the next adjacent electrode 13. The fuel and oxidizer are of course kept separated by the partition 21. With this arrangement it will be apparent that the electro-potential output of the left cell unit from *a* to *b* will be in series with the potential of the next unit cell and the latter, in turn, will be in series with the potential of the next unit cell from *c* to *d*. Hence, the three-cell combination will produce a voltage *a*—*d* equal to the combined potential of the three unit cells. It will also be understood that the number of such cells may be increased almost indefinitely to build up voltage to a desired level. A plurality of multi-cell units or cell packs may in turn be also connected in parallel if desired, so as to multiply the output current as well as the voltage to any extent required.

With the construction just described, the electrodes 11 and 13, which are commonly formed primarily of thin and often frangible materials such as sheets of porous carbon, or carbon and/or metal impregnated plastic sheets, will be supported structurally by the partitions and by each other. Furthermore, no external electrical connections in the whole

cell pack will be required except at the outer or terminal electrode elements such as *a* and *d*. By the use of thin plates of carbon or equivalent material for electrodes, and thin metal or metal connected partition-conductor elements, embossed only to sufficient depth to provide for passage of fuel and oxidant respectively, the multi-cell unit may be very compact. For example, the electrodes, e.g. carbon plates, may be of the order of 1/16" or so in thickness or in the range of about 0.05 to 0.10", with ordinary materials, and the partitions may be of even lesser thickness. The electrolyte layers likewise may be very thin so that a large number of cell units may be packaged within a relatively small volume. These electrolyte layers are shown as liquid filed spaces, and spacers are preferaby provided to support the rather fragile electrodes while not displacing the electrolyte to any substantial extent from the electrode surfaces. Instead of liquid, the electrolytes may be of other types such as impregnated porous materials. By choice of suitable construction and use of electrode materials which are less frangible than carbon plates, such as impregnated plastic or fabric sheets, even further reduction in thickness can be achieved.

Referring now to Fig. 2, a small fragment 13*a* of a fuel electrode is shown for illustrative purposes and not by way of limitation. The plate 13*a* has a pore 13*b* of such diameter that gaseous or liquid fuel will pass into the pore against the opposing surface tension or pressure of the electrolyte which as shown here forms a meniscus 13*c*. If the pore 13*b* is assumed to be of proper size, capillary action due to surface tension and wetting properties of the electrolyte will not drive the electrolyte too far into the body of the electrode, and a three-point or three-element contact between a particle or site of catalyst 13*d*, the fuel in the pore opening, and the electrolyte meniscus 13*c* may be established, say at points *x* and *y*. This may be assumed to result in a reaction which causes electron displacement and also produces a particle *z* of carbon dioxide (with carbonaceous fuel). Such particles of CO_2 may diffuse through the electrode or may coalesce and form bubbles which may rise in the electrolyte and pass out of the system. Suitable catalysts are known in the art and various catalytic materials can be used, as is well understood. It will be understood that the details of Fig. 2 are illustrative only and not limiting as to theory or principle of operation.

In order to keep the fuel cell operating efficiently, an excess of oxidizing gas—air is usually preferred—normally will be passed through the cell. Also an excess of fuel may be passed along the other side of each partition 21, the fuel of course being recycled to prevent waste as shown by legend in Fig. 1. The detailed means for directing producing and controlling the flow of fuel and of oxidant form no part of this invention.

Fig. 3 shows a somewhat similar arrangement to Fig. 1 but with only two adjacent pairs, respectively, of oxygen or oxidizer electrodes 31 and fuel electrodes 33. Between these are placed partition-conductor elements 35. These elements 35 are formed of, or comprise electrically conductive deformable sheets embossed on both sides with protuberant elements 37, which establish and maintain electrical contact with the adjoining electrode. At the same time, the embossed construction permits passage of gaseous or vaporized fuel along the face and through the porous body of the fuel electrode 33 and passage of air or other oxidizing gas along and through the oxidizer electrode 31. The elements 37 are resilient to maintain good contact. The air or oxidizer fluid may be drawn through the cell and into a duct 39 connecting to a suitable evacuating pump, or it may be forced into the cell, e.g. from an opposite direction as may be desired. Likewise, the fuel may be supplied through a duct 41 and as mentioned above, may be and preferably is recycled when supplied in excess. It may be desirable to supply fuel in excess and to recycle it through a suitable heat exchanger, not shown, to control the fuel cell temperature.

In Fig. 3, the two electrodes of each of the fuel cells shown, which cells will be understood to be only part of a series (additional units not being shown), are separated by the electrolyte layer 43. The electrolyte, shown as a liquid in this instance, may be supplied or withdrawn through line 44 to keep it at proper level. The voltages produced by the separate individual cell units which are shown only incompletely, are additive. That is to say, the cell units here again are connected in series and conductor leads need to be attached only to the end electrodes of the cell package or multi-unit.

In all the embodiments so far described, the embossings or grid formations are preferably such as to insure good circulation of the fluid, oxidizer or fuel, to all parts of the electrodes. They may be patterned so as to assist in directing the flow.

Fig. 4 shows a face or elevational view of a partition 72 which is so embossed as to make a plurality of spaced protuberances 71, each of which is flexible and resilient. This is done by taking a thin flat plate 72, e.g. a resilient metal foil, and pressing it in suitable dies to form a series of concentric deformations 71, each having a top inner circle or cap element 73, which actually makes contact with an electrode surface. The cap is surrounded by a sloping annular surface 74 and that surface, in turn, is surrounded by a

relatively depressed annular surface 75. Additional folds may be made in the metal, if desired, by additional concentric lines of deformation, so as to accomplish the purpose of having these elements quite resilient and flexible. The whole construction should be light in weight and inexpensive, consistent with liquid tight and electric conductivity requirements. With this arrangement, a thin metal such as a fairly heavy aluminum, brass or copper foil, or other very thin sheet material of suitable conductivity and resilience may be formed to serve as a combined electrode contactor and partition. In use, the caps 73 are pressed resiliently against the adjoining electrode surfaces so as to maintain good electric contact at all times, even when the cell operating temperature changes and differential expansion of various cell elements occurs.

As shown in Figs. 4 and 5, the protuberances 73 project primarily from one face of the metal. In between these, other protuberances 76 project rearwardly, Fig. 5. These are similar but reversed in direction so as to afford a space on either side of the sheet for the passage of the fuel or oxidizer as may be required, to the appropriate electrode. The reversed embossings have sloping and more or less conical surfaces 77 similar to elements 74 and concentric annular depressions 78.

The pattern of the embossing just described may be altered to direct flow or distribute flow as needed so as to insure efficient utilization of the whole electrode surface. If desired, the embossing pattern may form divergent patterns from the fuel or oxidizer inlet, for example, to lead the reactant material readily to cover the whole electrode surfaces. The flow space on either side of plate 72 may be equal or unequal, depending on fuel and air flows.

Referring to Fig. 6, there is shown another arrangement which is essentially like Fig. 3, except that the electrodes 81 for the air and 83 for the fuel are formed with finely serrated surfaces to increase very substantially their surface area. Such cutting or serrating operations may impair the strength of electrodes, giving need for lateral support, but they also quite substantially increase the surface area. Therefore, their design increases the current which can be produced from a given electrode. Thus, if the angle of the grooves 85 is A as shown in Fig. 6, and the distance between adjacent serrations is D, the surface area is increased by a factor of

$D/\mathrm{Sin}\,\frac{A}{2}$. D is preferably very small, since the thin carbon electrodes cannot be deeply grooved. If the angle A then is 40° for example, $\frac{A}{2}$ is 20° and the sine of this angle being about 0.34 means that the surface area will be multiplied by approximately a factor of 3. It will be appreciated that this does not necessarily mean that the current output will be increased three-fold since porosity of the electrode and availability of catalyst sites thereon are also important factors. However, the backing of conductor elements having closely spaced protuberances such as indicated at 87 and 88, by plates 89, gives the needed structural support to these electrodes, carries away the current with minimal losses, and makes their use feasible where in many other situations they could not be employed at all.

Figs. 7 and 8 show another arrangement of exaggerated thickness where adjoining oxidizer electrode 91 and fuel electrode 93 are contacted by resilient contact elements 95 mounted in a fluid tight partition element 97. The latter may be itself a conductor or not, but it is provided with conductive contacts 95 which connect the electrodes together. Since no outside connections are needed, except at terminal electrodes of a cell pack, the elements 95 need be adequate only to carry the current from one electrode to the next with minimal resistance. A terminal conductor would connect all members 95 together with a conductor element.

Another modification is shown in Fig. 9 wherein two pairs of adjoining air and fuel electrodes 101 and 103 are connected respectively to the appropriate neighbor electrode, the assembly including fluid tight partition members 105 equipped with a number of spaced conductor elements consisting of light resilient coil springs 107. These spring members are readily compressible and they give lateral support to the electrodes as well as providing for good electrical equalization and discharge of the voltages and currents produced in the cell units. In other respects the arrangement here is the same as in Figs. 1, 3 and 6.

Finally, in Fig. 10, there is shown an alternative arrangement related to that of Figs. 7 and 8, except that here the fluid tight partitions 111 are equipped with folded or U-shaped contactors 112, each adapted to press lightly against adjacent fuel electrodes 113 and oxidizer electrodes 115. The arrangement is such that fuel can pass through the space 117 to the fuel electrode and air or other oxidizer along space 119 to the oxidizer electrode. The electrolyte in space 121 carries the ions which produce current in the middle cell unit. Only half cell units are shown at left and right. It will be understood that suitable fuel and air c nnections will be provided and that partitions 111 are arranged to prevent mixture of fuel and oxidizer which

would destroy the effectiveness of the cell.

Also in Fig. 10 are shown spacer elements 123 adapted to give lateral support to the electrodes without materially decreasing the contact between the electrolyte and the electrodes. These elements contribute substantially to the ruggedness of a fuel cell assembly, particularly when used in mobile apparatus or in locations where excessive vibration may be expected.

WHAT WE CLAIM IS:—

1. A fuel cell pack comprising a plurality of cells, each comprising a fuel electrode, an oxidizing electrode and electrolyte, arranged with electrodes of opposite polarity of adjacent cells juxtaposed to each other, and a separate and demountable partition separating each pair of adjacent cells, forming separate fluid-tight channels for the fuel and oxidizing medium between the partition and the appropriate electrode, each such partition comprising resiliently deformable lateral members of electrical conducting material on each side thereof adapted to contact the electrodes and provide a current conducting link between the said electrodes.

2. A fuel cell pack as claimed in claim 1 wherein a plurality of lateral members is provided on each side of the partition to concontact each of the electrodes at a plurality of points over its while surface area and allow free access of the fuel or oxidizing medium over substantially the entire surface of the electrode.

3. A fuel cell pack as claimed in claim 1 or claim 2 wherein the partition comprises a sheet of conducting material having a plurality of protuberances on each side thereof, said protuberances being adapted to contact the respective electrodes.

4. A fuel cell pack as claimed in claim 3 wherein the said protuberances are embossed in the sheet of conductive material.

5. A fuel cell pack as claimed in claim 1 or claim 2 wherein the said lateral members are resilient leaf spring or coil spring members of conducting material.

6. A fuel cell pack as claimed in claim 1 or claim 2 wherein the partition member is of nonconducting material and comprises a plurality of conducting contacting elements connected together in pairs on either side of the partition and adapted to contact said electrodes and provide electric conductive connection between them.

7. A fuel cell pack as claimed in claim 6 wherein the said lateral members are protuberances of conducting material on each face of the partition connected with each other in pairs through the partition.

8. A fuel cell pack as claimed in claim 6 wherein the said lateral members are resilienr members, e.g. leaf springs or coil springs on each side of said partition and connected to each other in pairs through said partition.

9. A fuel cell pack as claimed in any of the preceding claims wherein the face of the electrodes contacting the electrolyte is serrated or ribbed to increase the effective surface area in contact with the electrolyte.

10. A fuel cell pack substantially as hereinbefore described and illustrated in the accompanying drawings.

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FIG.1.

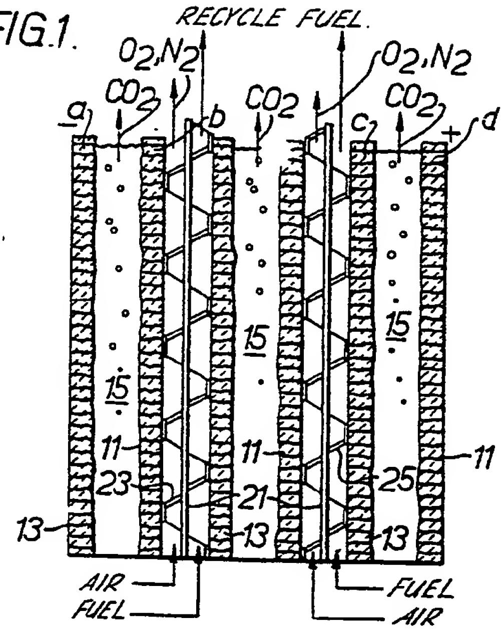


FIG.2.

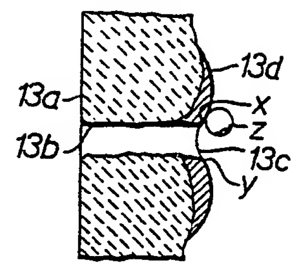


FIG.3.

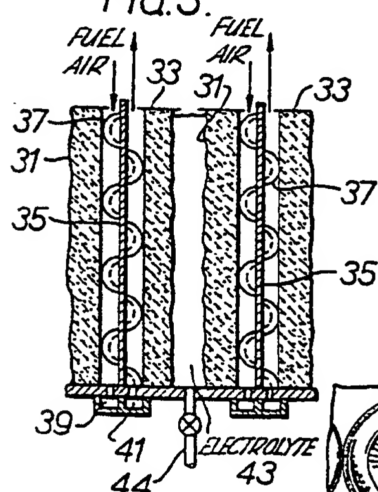
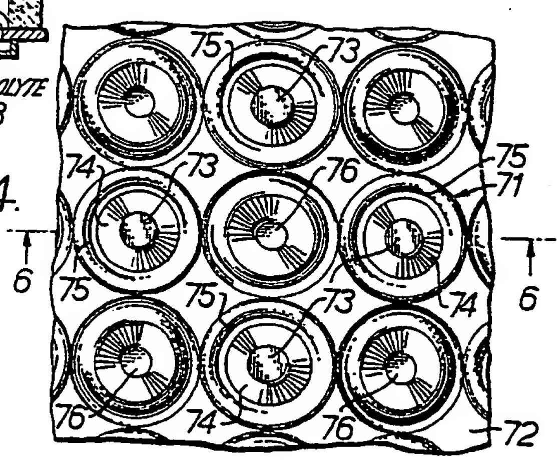


FIG.4.



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2 SHEETS

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SHEETS 1 & 2

3d
x
z
13c

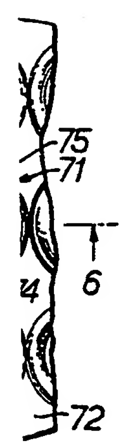


FIG.5.

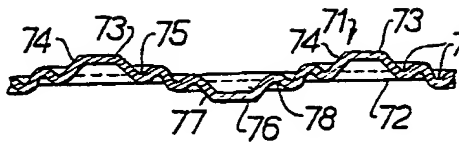


FIG.6.

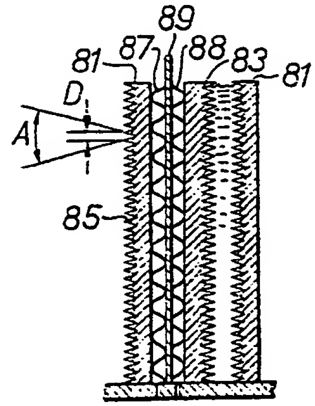


FIG.7.

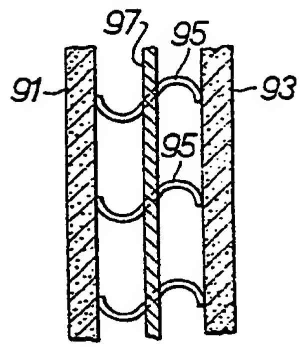


FIG.8.

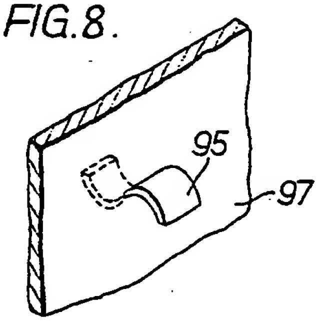


FIG.9 .

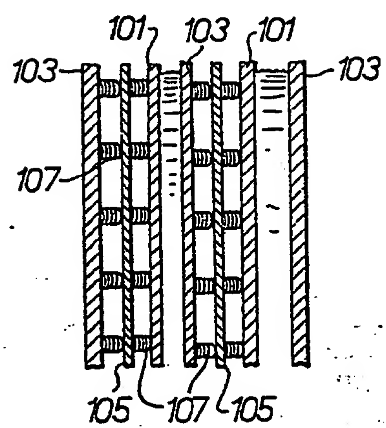
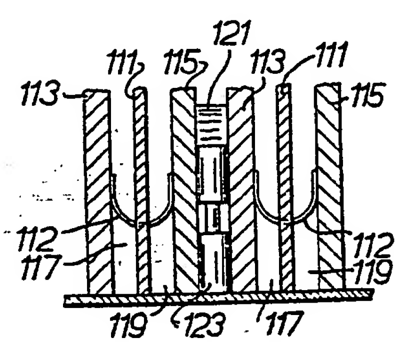


FIG.10.



966,407 COMPLETE SPECIFICATION
2 SHEETS This drawing is a reproduction of the Original on a reduced scale.
SHEETS 1 & 2

FIG.1.

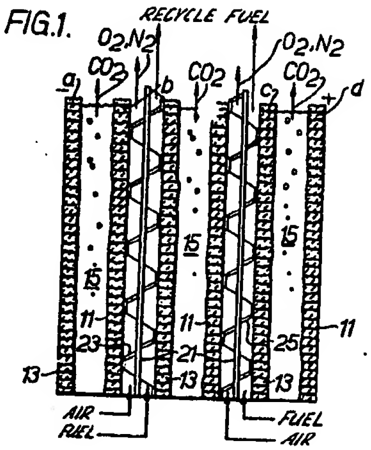


FIG.2.

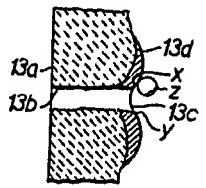


FIG.3.

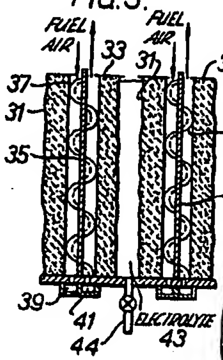


FIG.4.

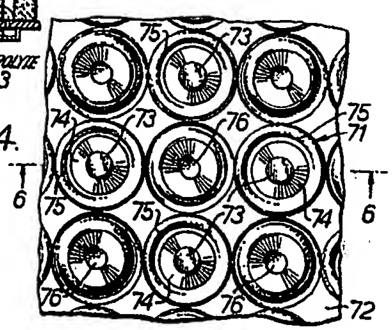


FIG.5.

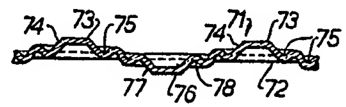


FIG.6.

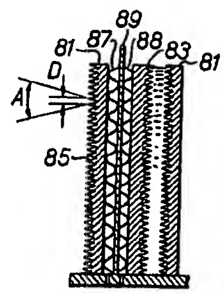


FIG.7.

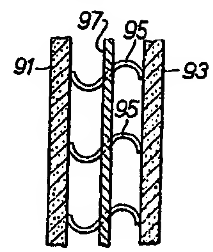


FIG.8.

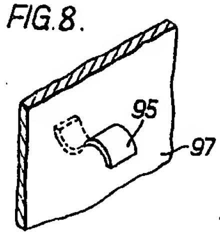


FIG.9.

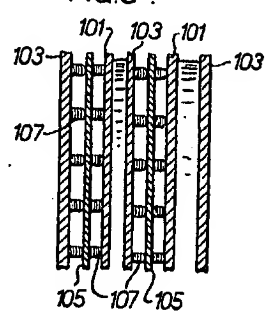


FIG.10.